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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LIX. No. 10. SUPPLEMENTARY NUMBER.

INVITATION OF LADIES TO THE ORDINARY MEETINGS OF THE SOCIETY.

The attention of Fellows is called to the fact that Ladies are only admitted to the Ordinary Meetings of the Society by special invitation of the President, sanctioned by the Council. The invitations are issued at the commencement of each Session.

THE LIBRARY.

The attention of Fellows is called to the following resolution of the Council at their meeting of 1896 November 13 :—

“All books must be actually returned to the Library on or before the second Friday in November in each year, and not taken out again till the following Friday without special permission.”

The present number of the *Monthly Notices* being the last of Vol. LIX., Subscribers (not Fellows) are requested to take notice that the subscription for Vol. LX. (10s., including postage) has now become due, and should be forwarded to the Assistant-Secretary, Mr. W. H. WESLEY, Burlington House, London, W., on or before the 1st of December next; otherwise it will be considered that the subscription has not been renewed.

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LIX. SUPPLEMENTARY NUMBER, 1899. No. 10

Comparisons of the Geocentric Places of Mercury, Venus, Mars, Jupiter, and Saturn, calculated from the Tables of the American Ephemeris Office, with their places calculated from Le Verrier's Tables, for the year 1901. By A. M. W. Downing, M.A., D.Sc., F.R.S.

The geocentric places of the planets named above, with the exception of those of *Mars*, as given in the *Nautical Almanac* for 1901, are calculated from the American Tables: the tables of the Sun, *Mercury*, and *Venus* having been prepared by Professor Newcomb, and those of *Jupiter* and *Saturn* by Mr. G. W. Hill. The corresponding geocentric places in the *Connaissance des Temps* for 1901 are from Le Verrier's Tables. Except for *Mars*, the comparisons have been made by reducing the quantities given in the *Connaissance des Temps* from Paris noon to Greenwich noon; and then finding the differences between the reduced quantities and the corresponding quantities in the *Nautical Almanac*. This is done for intervals of eight days throughout the year, and the results are exhibited in the following tables. For the right ascensions the discordances are given in arc of a great circle, as well as in time, to render them comparable with the discordances in declination.

In the case of *Mars*, Newcomb's Tables of this planet were not ready in time for adoption in the preparation of the *Nautical Almanac* for 1901, and it is therefore necessary, in this case, to compare the geocentric places of the *Connaissance des Temps* for 1901 with those of the *American Ephemeris* for the same year (in the calculation of which manuscript tables based on Newcomb's corrected elements were used), in the way indicated above, and thus to obtain the corrections to Le Verrier's Tables of *Mars*. The corresponding corrections to Le Verrier's longitudes of the Sun in 1901 were published in *Monthly Notices*, vol. lvii. p 43.

MERCURY, 1901.

Corrections to Le Verrier's Tables.

Day. 1901.	R.A.		Dec.	Day. 1901.	R.A.		Dec.
	Time. s	Arc. "			Time. s	Arc. "	
Jan. 2	+04	+05	-01	July 5	-16	-23	+09
10	+03	+04	+01	13	-15	-22	+08
18	+05	+07	00	21	-08	-11	+05
26	00	00	-01	29	-03	-04	+02
Feb. 3	-02	-03	-02	Aug. 6	-05	-07	+02
11	-01	-01	-04	14	-09	-13	+02
19	00	00	-05	22	-08	-12	+04
27	+03	+05	-05	30	-04	-06	+01
March 7	+03	+05	-01	Sept. 7	-02	-03	00
15	-01	-01	00	15	-01	-02	-02
23	-02	-03	-02	23	+01	+01	00
31	-01	-01	+01	Oct. 1	00	00	+01
April 8	-01	-01	+02	9	-02	-03	-02
16	-01	-02	+02	17	-03	-04	00
24	-02	-03	+01	25	-02	-03	-02
May 2	-02	-03	-01	Nov. 2	+02	+03	-07
10	-06	-09	-01	10	00	00	-07
18	-08	-11	-04	18	-05	-07	-02
26	-08	-11	-03	26	-05	-07	-02
June 3	-06	-08	00	Dec. 4	-01	-01	-02
11	-05	-07	+02	12	+01	+01	00
19	-07	-10	+06	20	+03	+04	-02
27	-12	-17	+08	28	+03	+04	-01

VENUS, 1901.

Corrections to Le Verrier's Tables.

Day. 1901.		R.A. Time. s	Arc.	Dec.	Day. 1901.		R.A. Time. s	Arc.	Dec.
Jan.	2	-04	-06	-10	July	5	-09	-13	+06
	10	-02	-03	-11		13	-07	-10	+04
	18	-01	-01	-11		21	-08	-12	+03
	26	00	00	-13		29	-06	-09	+01
Feb.	3	+01	+01	-12	Aug.	6	-05	-07	-02
	11	+01	+01	-09		14	-05	-08	-04
	19	+01	+01	-08		22	-04	-06	-06
	27	00	00	-08		30	-05	-08	-07
March	7	00	00	-05	Sept.	7	-05	-07	-09
	15	-01	-01	-05		15	-05	-07	-11
	23	-02	-03	-05		23	-05	-07	-11
	31	-05	-08	-02	Oct.	1	-03	-04	-12
April	8	-06	-09	00		9	-02	-03	-11
	16	-07	-10	00		17	-03	-04	-10
	24	-09	-13	+01		25	-02	-03	-07
May	2	-12	-17	+02	Nov.	2	+01	+01	-05
	10	-12	-17	+03		10	+01	+01	-02
	18	-12	-17	+05		18	+01	+01	+03
	26	-13	-18	+07		26	+02	+03	+05
June	3	-14	-19	+08	Dec.	4	+05	+07	+09
	11	-10	-14	+08		12	+05	+07	+16
	19	-11	-15	+08		20	+03	+04	+21
	27	-10	-14	+08		28	+09	+13	+24

MARS, 1901.

Corrections to Le Verrier's Tables.

Day. 1901.		R.A. Time. s	Arc.	Dec.	Day. 1901.		R.A. Time. s	Arc.	Dec.
Jan.	2	+03	+04	+04	Mar.	23	-02	-03	+10
	10	+02	+03	+06		31	-05	-07	+08
	18	+03	+04	+05	April	8	-04	-06	+08
	26	+04	+06	+05		16	-04	-06	+07
Feb.	3	+02	+03	+07		24	-04	-06	+07
	11	+01	+01	+07	May	2	-04	-06	+06
	19	+01	+01	+08		10	-04	-06	+05
	27	-01	-01	+08		18	-02	-03	+04
Mar.	7	-01	-01	+10		26	-03	-04	+04
	15	-03	-04	+10	June	3	-01	-01	+03

Day. 1901.		R.A.		Dec.	Day. 1901.		R.A.		Dec.
		Time. s	Arc.				Time. s	Arc.	
June	11	-02	-03	+02	Sept.	23	-03	-04	-03
	19	-02	-03	00	Oct.	1	-02	-03	-03
	27	-02	-03	+02		9	-03	-04	-03
July	5	-01	-02	+01		17	-03	-04	-03
	13	-01	-02	-01		25	-05	-07	-03
	21	00	00	-01	Nov.	2	-05	-07	-03
	29	-02	-03	+01		10	-05	-07	-04
Aug.	6	-03	-04	-01		18	-04	-05	-03
	14	+01	+01	-02		26	-05	-07	-04
	22	00	00	-02	Dec.	4	-05	-07	-05
	30	-01	-01	-01		12	-06	-08	-04
Sept.	7	-01	-01	-03		20	-04	-06	-06
	15	-02	-03	-04		28	-04	-06	-05

JUPITER, 1901.

Corrections to Le Verrier's Tables.

Day. 1901.		R.A.		Dec.	Day. 1901.		R.A.		Dec.
		Time. s	Arc.				Time. s	Arc.	
Jan.	2	+18	+25	00	July	5	+26	+36	-02
	10	+18	+25	00		13	+27	+37	00
	18	+16	+22	+02		21	+25	+35	-02
	26	+17	+23	+01		29	+25	+35	-02
Feb.	3	+18	+25	+01	Aug.	6	+24	+33	-01
	11	+19	+26	+02		14	+24	+33	00
	19	+19	+26	00		22	+23	+32	00
	27	+19	+26	00		30	+23	+32	-01
Mar.	7	+19	+26	+02	Sept.	7	+23	+32	+01
	15	+20	+28	+01		15	+22	+30	-01
	23	+20	+28	+01		23	+21	+29	00
	31	+22	+30	+02	Oct.	1	+20	+28	00
April	8	+21	+29	+02		9	+20	+28	-02
	16	+23	+32	+04		17	+20	+28	-01
	24	+23	+32	+04		25	+15	+21	-01
May	2	+24	+33	+02	Nov.	2	+19	+26	00
	10	+24	+33	-01		10	+18	+25	-01
	18	+23	+32	+02		18	+16	+22	+01
	26	+25	+35	+01		26	+16	+22	+01
June	3	+25	+35	+03	Dec.	4	+19	+26	+01
	11	+25	+35	+03		12	+18	+25	+01
	19	+26	+36	+01		20	+16	+22	00
	27	+26	+36	00		28	+17	+24	00

SATURN, 1901.

Corrections to Le Verrier's Tables.

Day. 1901.	R.A.		Dec.	Day. 1901.	R.A.		Dec.
	Time. s	Arc.			Time. s	Arc.	
Jan. 2	-24	-3'3	+0'4	July 5	-30	-4'2	+0'2
10	-25	-3'5	+0'2	13	-29	-4'0	+0'2
18	-25	-3'5	+0'2	21	-27	-3'8	+0'4
26	-28	-3'9	+0'2	29	-25	-3'5	+0'3
Feb. 3	-29	-4'0	+0'1	Aug. 6	-24	-3'3	+0'2
11	-30	-4'2	+0'1	14	-24	-3'3	+0'4
19	-32	-4'5	0'0	22	-23	-3'2	+0'3
27	-31	-4'3	+0'1	30	-22	-3'0	+0'3
Mar. 7	-31	-4'3	+0'1	Sept. 7	-20	-2'8	+0'5
15	-35	-4'9	0'0	15	-19	-2'6	+0'4
23	-35	-4'9	0'0	23	-19	-2'6	+0'3
31	-34	-4'7	+0'1	Oct. 1	-18	-2'5	+0'5
April 8	-36	-5'0	0'0	9	-19	-2'6	+0'5
16	-35	-4'9	0'0	17	-17	-2'3	+0'4
24	-35	-4'9	+0'1	25	-19	-2'6	+0'1
May 2	-35	-4'9	0'0	Nov. 2	-21	-2'9	+0'3
10	-34	-4'7	-0'1	10	-19	-2'6	+0'3
18	-34	-4'7	+0'1	18	-19	-2'6	+0'2
26	-32	-4'5	0'0	26	-20	-2'8	+0'2
June 3	-34	-4'7	+0'1	Dec. 4	-20	-2'8	+0'2
11	-33	-4'6	+0'1	12	-22	-3'1	0'0
19	-30	-4'2	+0'1	20	-21	-2'9	0'0
27	-30	-4'2	+0'1	28	-22	-3'1	+0'1

*Note on the Geographical Position of the University Observatory,
Oxford.* By A. J. Walker, M.A.

[Introductory note by H. H. Turner, Savilian Professor.—
Since my appointment at the end of 1893 the Astronomical work
of the Observatory has been that of the Astrographic Chart, and
no precise determination of the position has been required. It
has been realised, however, that the accepted position is defec-
tive, and as soon as opportunity offers a more exact determi-
nation will be made. Meanwhile the following statement by
Mr. Walker summarises the available information. I am much

obliged to him for the time and trouble he has expended in making these measurements.—H. H. T.—1899 August.]

In *Astronomical Observations made at the University Observatory, Oxford*, No. 1 (published in 1878), at p. vi of the introduction will be found the following statement: "The geographical position of the Observatory, as given in a communication from the Ordnance Survey Department, under the direction of Col. Sir H. James, is as follows:—

Longitude West of Greenwich	$1^{\circ} 15' 5''.991$
North Latitude	$51^{\circ} 45' 34''.152."$

This is the position which has appeared in the *Nautical Almanac* ever since, the longitude of course being expressed in time— $5^m 0^s.4$ west. The *Almanac* for 1898 gives as the source of its information Lancaster's *Liste General*. This was the first year that the *Almanac* contained the source from which the positions of observatories were derived.

In 1897 some Z.D. observations made with the Barclay Transit Circle of the University Observatory exhibited considerable discordances. In recording these observations Prof. Turner wrote: "These discordances could not be attributed to any known cause. Later it was found that the O.G. was possibly loose (see collimation observations). But the matter requires clearing up. The assumed latitude is possibly to some extent in error, though this cannot explain the whole discordances. From differential observations on the Radcliffe Observatory it would appear that the latitude should be $1''$ or $2''$ smaller."

Unfortunately the communication from the Ordnance Survey Department does not seem to have been preserved; at any rate, it cannot now be found. There is, however, among the records of the Observatory a paper purporting to show the orientation of the building, and stating that the orientation is 5 inches out in the length of the building. This was apparently communicated by the Ordnance Survey Department.

The position of the University Observatory, carefully taken from the 6-inch Ordnance Map (R.F. $\frac{1}{10560}$), is:—

Longitude $1^{\circ} 15' 6''.6$ or $5^m 0^s.5$ W. Latitude $51^{\circ} 45' 33''.8$ N.,

or $0^s.6$ ($0^s.1$ nearly) = 37.7 feet further west and $0''.4$ = 40.6 feet further south than the position furnished by the Survey Department. But it would not be difficult to make an error of $0''.2$ in taking off the position, and it is difficult to exactly define the point on the map which represents the position of the Transit Circle.

But the position of the University Observatory may be

obtained in another way. Its bearing and distance from the Radcliffe Observatory may be determined, and the difference of latitude and longitude so obtained may be applied to the received position of the latter Observatory. There is, however, apparently no record of this having been done till 1897. Certain differential observations made in that year have already been mentioned. Measurements have now been made upon the 25-inch Ordnance Map (R.F. $\frac{1}{25000}$), and from these the University Observatory would appear to be 358 feet to the south and 2,425 feet to the west (true) of the Radcliffe Observatory. The first of these distances is equivalent to a difference of latitude of $3''\cdot5$, while the second corresponds to a difference of longitude of $38''\cdot5$ or $2^s\cdot6$. If we take the position of the Radcliffe Observatory from the N.A. for 1898 we have :—

	Longitude. m s	Latitude.
Position of Radcliffe O. from N.A.	5 2 ^s 6 W.	51° 45' 35 ^s 4 N.
Diff. Long. and Lat. from Map	—2 ^s 6	—3' 5
Resulting position of U.O.O.	5 0 ^s 0 W.	51 45 31 ^s 9 N.
Position of U.O.O. from N.A.	5 0 ^s 4 W.	51 45 34 ^s 2 N.
Difference	0 ^s 4 = 377 feet	2' 3 = 233 feet

If the relative position of the two Observatories be correctly laid down on the 25-inch Ordnance Map, it follows that the position of the University Observatory furnished by the Ordnance Survey Department differs considerably from that obtained by astronomical observations, unless indeed a large error has been made in taking the measurements from the map.

Apart from any mere inaccuracy in writing down the result of the measurements, the scale of the 25-inch map is such that a greater error than 5 feet should not be possible in taking off a distance, but it is of course not very easy to say which are the points on the map which represent the position of the Transit Circles of the two Observatories.

A measurement of the difference of latitude on the 6-foot map gave 352 feet—a difference of 6 feet from that obtained from the 25-inch map.

It now remains to check the distance between the two Observatories obtained from measurement upon the Ordnance Map, and to consider with what accuracy the position of the Radcliffe Observatory given in the *Nautical Almanac* has been determined. The second question will be first considered.

From the *Radcliffe Observations* some information can be obtained as to the determination of the position of the Observatory. In the 1841 volume (published 1843) we find the following, p. xv : “In all interpolations from the *Nautical Almanac*, the longitude of the Observatory has been considered $5^m 2^s\cdot6$ W. of Greenwich, which is the result of a most careful Chronometrical

determination in the course of 1842 by the Rev. Richard Sheepshanks, the details of which I hope will be soon published." They were apparently not published in the Radcliffe Volumes, and nothing regarding them has been found in either the *Philosophical Transactions*, the *Proceedings* of the Royal Society or the *Monthly Notices* or *Memoirs* of the Royal Astronomical Society. Mr. Sheepshanks died in 1855. See memoir in *Proceedings Royal Society*, where various longitude determinations carried out by him in 1843 and one or two other years are mentioned, but none in 1842.

The longitude has also been obtained by observations of the Moon's R.A. at Oxford and Greenwich from 1864 to 1868 inclusive, and in the 1868 volume of *Radcliffe Observations* we read, p. xxxv: "The most probable result is $5^m 3^s.66$ W., and this is in excess of the received longitude by $1^s.06$. It must not, however, be assumed that the latter is erroneous to that amount . . ."

It would seem as if preparations were at one time made for a telegraphic determination of the longitude. It is said that a wire was laid from the Observatory to the Great Western Railway telegraph system. People now living have seen the wire dug up in the Observatory grounds and in the streets. There is also an old chronograph in the Library, which seems to point to preparations for a telegraphic determination, but no reference to the matter has been found in the annual volumes, and nothing is known about it by the present staff of the Observatory.

In 1840 the latitude adopted was $51^{\circ} 45' 36''.0$, and this appeared as the latitude in the *Nautical Almanac* for a long time—in fact, until the present value was substituted in 1898. In 1880 $51^{\circ} 45' 35''.16$ was adopted, and used up to 1888. In the 1888–1889 volume, we find the following remarks, p. xiv: "The assumed position of the Transit Circle of the Observatory employed in the reductions has been

Longitude $5^m 2^s.6$ West of Greenwich.

Latitude $51^{\circ} 45' 35''.16$ North.

The latitude used in these reductions is that which has been adopted in the Annual Volumes since 1880, but is not that which is adopted in the General Catalogue of Stars for 1890, which is $51^{\circ} 45' 35''.39$."

It may here be remarked that the Carrington Transit Circle was brought into use in 1862, having been mounted in exactly the same position as the old Transit. Previous to the erection of the Transit Circle the observations from which the values of the latitude were obtained were made with the Mural Circle. The values of the latitude obtained from observations made in various years have been taken from the Annual Volumes, and are given on next page.

Year.	Latitude.			
1840	51°	45'	35''	85
1841				35'97
1842				35'70
1843				35'82
1854				35'31
1861				35'88
1862				35'85
1863				35'73
1864				35'50
1865				35'28
1880			35'17 with a weight of	53'6
1881			34'95	76'7
1882			35'24	111'5
1883			35'23	55'6
1884			35'49	29'5
1885			35'43	25'1
1886			35'67	5'1
1887			35'73	19'9

For further information regarding the value adopted for the 1890 Catalogue see the introduction to the Catalogue.

In order to check the measurements taken from the 25-inch Ordnance Map, the following measurements were made on the ground in 1899 May

On May 18 a line was set out northwards towards the cricket pavilion with the Barclay Transit Circle for a distance of 575 feet, trees preventing its being carried any further. The line was first set out with ranging rods, it being possible to see these pretty distinctly with the Transit Circle when a piece of cardboard with a small hole in it was placed in front of the O.G. The rods were then replaced by pegs into which copper tacks were driven for the purpose of more accurately defining the line.

Then, by means of a right-angled prism, the point was found in the meridian line in which that line was cut at right angles by a line from the centre of the globe on the top of the tower of the Radcliffe Observatory. The distance from this point to the Barclay Circle was found by the tape to be 359 feet, differing but 1 foot from the distance as measured on the 25-inch Ordnance Map.

The distance was then measured between two points on the meridian line from both of which the Radcliffe Observatory was visible. The mean of two measurements (which differed by $\frac{1}{2}$ inch) with a 100-foot steel tape gave 334 feet $0\frac{1}{4}$ inch. The angle formed at each end of this base with the globe on the Radcliffe

tower was then measured several times on different days with a 5-inch theodolite by Messrs. T. Cooke & Sons, of York.

The distance between the centre of the Radcliffe hall (which is assumed to be directly below the centre of the globe) and the Radcliffe Transit Circle was measured with a steel tape and found to be 44'62 feet.

As a further check, two traverses were made with the 5-inch theodolite and Chesterman 100-foot steel tape between the two Observatories, and by the kindness of the Radcliffe Observer it was possible to carry them right up to the Radcliffe Transit Circle. Owing to bad weather and difficulties caused by traffic, these measurements were made on different days and at different times of day. Every line was measured twice when possible. In most cases the back station was observed first, the theodolite being first set to zero. The compass was used as a check in the first traverse, and showed the presence of a good deal of local attraction. Details of the measurements follow :—

Summary of Results of Measurements.

Difference of Latitude. Feet.	Departure. Feet.	
357'65	2419'47	1st Traverse
358'95	2418'67	2nd „
356'47	2417'92	1st Triangulation
356'64	2419'02	2nd „
4 / 29'71	35'08	
Mean 357'43	2418'77	
357'43	2418'77	From the various measurements.
358'00	2425'00	From the 25-inch map.
352'00	„ „ 10-foot „	

Taking the difference of latitude as 357'43 feet and the departure as 2418'77 feet, and the value of 1'' of latitude as 101'38 feet and 1'' of longitude as 62'92 feet, we have :—

Difference of Latitude 3''53.	Difference of Longitude 38''44 = 2'56.
Distance 2445'0 feet.	Bearing N. 81° 35' 40'' W.

Hence the University Observatory is :

3''53 South of the Radcliffe Observatory	
and 38''44 } East „ „ „	
or 2'56 }	

while the Radcliffe Observatory bears from it N. 81° 35' 40'' W. true, distant 2445 feet.

The measurements actually made on the ground agree, therefore, closely with those made on the 25-inch Ordnance Map, and

give what is practically precisely the same difference of latitude and longitude.

The difference between the position of the University Observatory obtained by applying this difference of latitude and longitude to the N.A. position of the Radcliffe Observatory and the position furnished by the Ordnance Survey Department is, then, $0^{\circ}.4$ in longitude and $2''.3$ in latitude.

On 1899 July 18 a letter was written to the Director-General of the Ordnance Survey, giving the same details substantially as those here given, and asking for information on the subject. This letter was acknowledged by return of post, and a reply, dated 1899 August 2, subsequently received. This reply is appended.

Ordnance Survey Office,
Southampton, 1899 August 2.

DEAR SIR,—The question raised in your letter of 18th ultimo has been investigated. Unfortunately, the data on which Sir H. James reported the latitude and longitude of the University Observatory, Oxford, cannot be found.

The positions of the University and Radcliffe Observatories as shown on our maps have been checked, and there seems no doubt as to their correctness; but the only satisfactory way of clearing up the discrepancies would be to connect the Observatories with the triangulation of the Ordnance Survey. This would take some time and entail some expense, and could not be undertaken without the sanction of the Board of Agriculture.

Yours faithfully,

DUNCAN A. JOHNSTON, Colonel.

A. J. WALKER, Esq.

The reply would seem to carry the matter very little, if any, further. Information was asked as to the difference between positions in or near Oxford as determined by geodetic operations and astronomical observations, but none is given. One would not naturally expect a large deflection of the vertical in Oxford. Clarke, however, remarks in his *Geodesy*, 1880, at p. 287, "The discordances resulted from the fact with which we are now familiar, that the observed latitude of any station, although from its surroundings it may be apparently quite free from any suspicion of local attraction, is yet liable to an error of one or two seconds. This amount is, indeed, often exceeded, and it is not very uncommon to find, as in the vicinity of Edinburgh, a deflection of gravity to the extent of $5''$. . ." Gillespie also remarks (*Higher Surveying*, 1897, at p. 196), "An examination of the local deflection of the vertical (plumb line) at latitude stations shows that the determination of astronomic latitude with an accuracy of about a quarter of a second is quite sufficient for most schemes of triangulation, being considerably within the limits of the ordinary deflections. A greater precision is necessary in locating state and national boundaries and determining arcs."

Variation of latitude, the range of which is apparently between $0''.2$ and $0''.7$, would not go far towards explaining a discrepancy of $2''.3$.

On the Optical Distortion of a Doublet Lens. By Captain E. H. Hills, R.E.

In the May number of *Monthly Notices*, Professor Turner has discussed the distortion of a doublet lens, and has shown that it is at all events probable that it is a negligible quantity over a field of 11° square.

In my investigation on the determination of longitudes by photography (*Memoirs R.A.S.* vol. liii.), it was necessary to satisfy myself, before applying the formulæ of reduction to the star places, that any possible optical distortion of the lens employed did not introduce a measurable factor into the results, and I accordingly carried out some experiments on this point.

The results I arrived at were practically identical with those reached by Professor Turner, but as I approached the subject by a different road it seems desirable to give a short account of the work. The method used was to set up the camera in a fixed position, and, leaving the lens open for a considerable time, a number of star trails were drawn across the plate. The curvature of these trails was then measured and compared with the calculated amount.

For convenience of computation, the camera was so arranged that the projection of the equator fell near the centre of the plate. This is not absolutely necessary, as the rigorous formulæ present no special difficulty; but, as will be seen immediately, the employment of a simple, approximate formula for the curvature does not introduce any appreciable error until the centre of the plate is moved many degrees from the equator.

The theoretical curvature of a star trail on the plate may be derived as follows:

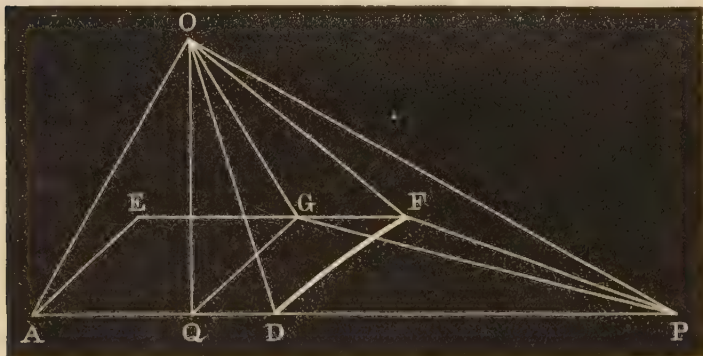


FIG. 1.

Q is the 'centre' of the plate—*i.e.* the foot of the normal from the centre of the lens on the plate.

O is the centre of projection—*i.e.* the optical centre of the lens.

AE is the projection of the equator.

P is the projection of the pole.

DF is any star trail.

The line EF is drawn on the plate parallel to AP at any arbitrary angular distance from it, and QG is parallel to AE.

Let

$$QOG = \theta.$$

$$OQ = \text{radius} = 1.$$

$$QOA = \text{declination of centre of plate} = \phi.$$

$$DOA = \text{declination of star} = \delta.$$

Then GF—QD is the curvature required.

We have

$$QG = \tan \theta.$$

$$QP = \cot \phi.$$

$$\tan QPG = \tan \theta \tan \phi.$$

$$= \tan \alpha.$$

In the triangle GOP

$$OG = \sec \theta.$$

$$OP = \text{cosec } \phi.$$

$$GP = \tan \theta \text{ cosec } \alpha.$$

$$\cos GOP = \frac{\sec^2 \theta + \text{cosec}^2 \phi - \tan^2 \theta \text{ cosec}^2 \alpha}{2 \sec \theta \text{ cosec } \phi}$$

but

$$\text{cosec}^2 \alpha = 1 + \cot^2 \alpha = 1 + \cot^2 \theta \cot^2 \phi.$$

Therefore,

$$\cos GOP = \frac{\sec^2 \theta + \text{cosec}^2 \phi - \tan^2 \theta - \cot^2 \phi}{2 \sec \theta \text{ cosec } \phi}$$

$$= \cos \theta \sin \phi.$$

$$= \cos \beta.$$

In the solid figure OGFP, taking the angles at G, we have

$$OGF = 90^\circ$$

$$FGP = \alpha$$

and angle between planes OGF, FGP = $90^\circ - \theta$.



FIG. 2.

Then, if B = angle between planes OGF, OGP,

$$\begin{aligned}\tan B &= \tan \alpha \cos \theta \\ &= \sin \theta \tan \phi.\end{aligned}$$

Again taking the angles at O, we have

$$\text{FOP} = 90^\circ - \delta.$$

$$\text{GOP} = \beta.$$



FIG. 3.

Then if C = angle between planes FOP, GOF

$$\sin C = \frac{\sin B \sin \beta}{\cos \delta}$$

and

$$\begin{aligned}\tan \frac{\text{GOF}}{2} &= \frac{\sin \frac{B+C}{2}}{\sin \frac{B-C}{2}} \tan \frac{90^\circ - \delta - \beta}{2} \\ &= \tan \frac{\gamma}{2}.\end{aligned}$$

We have therefore finally as the expression for the curvature—

$$\text{GF} - \text{QD} = \sec \theta \tan \gamma - \tan (\delta - \phi)$$

where

$$(1) \quad \tan \frac{\gamma}{2} = \frac{\sin \frac{B+C}{2}}{\sin \frac{B-C}{2}} \tan \frac{90^\circ - \delta - \phi}{2}.$$

$$(2) \quad \sin C = \frac{\sin B \sin \beta}{\cos \delta}.$$

$$(3) \quad \tan B = \sin \theta \tan \phi.$$

$$(4) \quad \cos \beta = \cos \theta \sin \phi.$$

The angle θ can be selected any convenient magnitude, say 5° , and it is then easy to construct a table of double entry, giving the value of the curvature at any distance from the centre. In practice, however, this is unnecessary. It is obvious that when ϕ is small the expression for the curvature becomes

$$\tan \delta (\sec \theta - 1),$$

and the difference between this approximate value and the true one will remain quite negligible even when ϕ amounts to many degrees.

Thus taking $\theta = 5^\circ$ and values of δ between 0° and 10° , it will be found that, even when $\phi = 8^\circ$, the difference between $\sec \theta \tan \gamma - \tan (\delta - \phi)$, and $\tan \delta (\sec \theta - 1)$ does not amount to a unit in the 7th place of decimals, *i.e.* does not exceed $0''.02$.

In taking the test plate there can be no possible difficulty in so adjusting the camera that the centre lies near the equator, and the theoretical curvature of a trail can then be deduced in the above simple manner.

As an example of the method the results obtained with an actual plate may now be given.

The lens in this case was a Zeiss anastigmat of 377 mm. focal length. The micrometer used read to $.001$ mm., equivalent to $0''.6$ of arc on the plate. An error of four times this amount, or between $2''$ and $3''$, is quite possible in any individual measurement.

The measures may therefore be taken as qualitative rather than quantitative, as it is obvious on inspection of the residuals that there is no measurable distortion over the field taken—namely, to a distance of about 9° from the centre, equivalent to a square plate of about $12\frac{1}{2}^\circ$.

Table Giving Results of Test of Zeiss Anastigmatic Lens.

$\begin{cases} r = 377 \text{ mm.} \\ \theta = 5^\circ \\ \phi = 24' \end{cases}$						
Star.	δ	Distance from Centre of Plate.	Curvature in Millimetres.			O—O in Arc.
			Observed.	Calculated.	O—C	
1	$-1^\circ 16'$	$0^\circ 52'$	.030	.030	$\pm .000$	$\pm 0''.0$
2	$-2^\circ 0'$	$1^\circ 36'$	.049	.050	$-.001$	$-0''.6$
3	$-2^\circ 40'$	$2^\circ 16'$	.067	.066	$+.001$	$+0''.6$
4	$+3^\circ 0'$	$3^\circ 24'$	.080	.075	$+.005$	$+2''.9$
5	$+4^\circ 3'$	$4^\circ 27'$	.099	.102	$-.003$	$-1''.7$
6	$-4^\circ 54'$	$4^\circ 30'$	.121	.124	$-.003$	$-1''.7$
7	$+5^\circ 52'$	$6^\circ 16'$	.149	.148	$+.001$	$+0''.6$
8	$-5^\circ 58'$	$5^\circ 34'$	.151	.150	$+.001$	$+0''.6$
9	$+6^\circ 15'$	$6^\circ 39'$	.165	.159	$+.006$	$+3''.4$
10	$+7^\circ 23'$	$7^\circ 47'$	.188	.186	$+.002$	$+1''.1$

As Prof. Turner has pointed out, the effect of refraction is practically eliminated by taking the measurements in the form of differences of curvature of two trails. This was done in the above example. The trail of a known star (δ . *Orionis*), near the centre of the plate, was taken as the fiduciary line from which the measurements were made, and the deduced curvatures were

then corrected by adding or subtracting the calculated curvature of this trail. These residuals will no doubt at first sight appear large to those accustomed to work with instruments of long focal length, but it must be borne in mind that these same quantities expressed in linear measurement, which is really fairer for purposes of comparison, are extremely small. The unit of measurement used—namely, .001 mm.—certainly represents the extreme limit of accuracy, if indeed it be not beyond it, that can be obtained from any stellar photograph. If a more liberal standard of accuracy were adopted the appearance of the residuals would be correspondingly improved. Thus taking the standard of the astrographic plates and carrying the measurements, as is done with them, only to a limit of .005 mm., it will be seen at once that nearly all the residuals would be zero.

It may further be noted that, as any distortion which is linear in r will disappear in the reduction to rectilinear co-ordinates, we are entitled to assume that value of r which will make the sum of the residuals a minimum, provided always that there be sufficient stars on the plate to give a real value of r . In this example, as all the residuals are practically within the limits of possible errors of measurement, a correction of the assumed value of r would be unnecessary and hardly justifiable.

List No. 12 of Nebulæ discovered at Lowe Observatory, Echo Mountain, California, for 1900'0. By Lewis Swift.

No.	Date 1898.	R.A. h m s	Dec. ° ' "	Description.
1	May 24	0 4 10	-32 49.9	vF, vS, R, unequal D * n.
2	24	0 5 30	- 7 58.3	eeeF, vS, R, bet $7\frac{1}{2}$ * n and 9 ^m * s, eee dif.
3	22	0 29 40	-30 32.9	eeeF, S, R, wide D * close p point to it. Not 174.
4	Nov. 19	0 53 0	-17 ?	pF, vS, $7\frac{1}{2}$ * np, F * near s p.
5	May 24	1 0 0	-27 56.4	eF, pS, close to 3 st like belt of Orion.
6	Oct. 12	1 4 0	-29 6.6	cB, pS, R, 3 8 ^m st near.
7	Sept. 20	1 28 0	-14 0.8	eeF, R, S, 1E, 8 ^m * n, e dif.
8	Oct. 10	1 54 15	-28 16.5	eeF, S, R, 8 ^m * S, lf.
9	Previous	11 49 ?	- 5 ?	eeF, 1E, v small, 3 B st in line n, also circle of st n. Saw it twice, failed once.
10	June 24	12 15 5	+61 15.0	eeeF, S, $7\frac{1}{2}$ and 5 ^m st in field, p of 2. One of my faintest nebulæ.
11	24	12 15 35	+61 15.0	vF, pL, R, $7\frac{1}{2}$ * south, f of 2.
12	Aug. 19	15 29 ?	+ 6 21.0	eeeF, L, R, eee dif.
13	19	15 50 ?	+ 6 19.0	eF, S, R, bet 8 ^m * f, and curve of st p.
14	16	19 41 20	-33 34.0	eeeF, eeS, eee dif sev F st near.

No.	Date 1897.	R.A. h m s	Dec. ° ' "	Description.
15	Sept. 11	19 59 0	-44 19'3	eF, S, R, 3 or 4 st f, form with the neb, a circle, sp of 2.
16	17	19 59 30	-43 59'3	vF, pS, R, bet a wide D * f and a * np, nf of 2.
17	11	20 17 25	-38 33'9	eF, pS, R, bet 2 8 $\frac{1}{2}$ ^m st nf and sp.
18	8	20 19 0	-30 11'8	vF, C, S, R, 2 st nr sf, point to it. Sp of 2.
19	8	20 19 25	-30 1'8	eeF, C, L, R, bet 2 groups of B st sf, and np, nf of 2.
20	Aug. 18	20 22 20	-32 1'9	pB, pS, R, nearly bet 2 st with dist. companion.
21	Sept. 11	20 24 0	-38 32'9	eF, pS, R, bet 2 8 $\frac{1}{2}$ ^m st nf and sp.
22	July 26	20 34 10	-30 11'6	eeF, eS, eE, F * with dist. com. nr sf, point to it, np of 2.
23	26	20 34 30	-30 12'6	eeeF, vS, cE, ee dif, sf of 2.
24	Sept. 8	20 44 10	-30 11'8	vF, pS, R, 8 ^m * in margin of field n.
25	Aug. 19	21 18 0	-41 3'3	vE, vS, R, * with dist. com. n and s.
26	July 24	21 36 30	-39 27'0	eeeF, vS, R, 5 or 6 st nr sp, v dif.
27	Sept. 15	21 42 55	-34 7'0	eeF, S, R, wide D * points to it, sev pB st sf and np.
28	Aug. 18	21 44 50	-31 26'8	vF, S, LE.
29	July 23	21 53 0	-39 52'8	vF, L, LE, 2 B st point to it, nearest in contact.
30	Sept. 8	21 53 0	-27 51'5	eF, S, R, 6 $\frac{1}{2}$ ^m * same parallel fol- lows 63°.
31	July 26	21 57 0	-35 27'1	pB, pS, R, 3 st in line nr nf.
32	Oct. 16	21 57 26	-34 17'0	pF, pS, R, in vacancy.
33	July 26	22 7 25	-37 22'5	vF, L, R, * close S, B * sp.
34	Sept. 20	22 9 30	-36 20'3	pB, C, S, F * in contact sf, sev pB st form segment of large circle.
35	July 19	22 9 35	-37 22'4	pF, pS, LE, bet 2 st in meridian, 8 $\frac{1}{2}$ ^m * sp, np of 2.
36	19	22 10 25	-37 20'4	eeF, S, R, F * nr p, 8 ^m * np, sf of 2.
37	26	22 18 5	-27 58'5	eF, pS, R, 8 ^m * p.
38	Oct. 6	22 26 0	-25 52'6	eeF, pS, R, bet 2 st, a dozen st in margin of field f, form semicircle 4 st np a curve, one D, sp of 2.
39	6	22 26 10	-25 10'3	eeeF, pL, R, no * nr, trapezium, nf of 2.
40	July 19	22 34 20	-30 31'6	eeeF, eeeS, eeeE, eee dif, a line. 8 ^m * np.
41	19	22 49 0	-37 53'5	eeF, pS, R, 9 ^m * nr sp, ee dif.
42	Aug. 22	22 49 40	-34 22'0	eeeF, pS, R, bet a * p and a wide D nf, 8 ^m * f, eee dif, np of 2.
43	22	22 52 30	-34 17'0	pF, pS, vE, bet 2 st.
44	July 26	23 13 0	-10 50'6	eF, S, R, 3 or 4 F st nr sp.
45	24	23 47 0	-29 11'4	vF, eS, R, 3 st in line p, one D.

Lowe Observatory:
1899 July 9.

The Magnitude of η Argûs, 1899. By R. T. A. Innes.

The comparison stars for η Argûs given in the *Uranometria Argentina* only go to the 7.60 magnitude, and fainter magnitudes are now required.

For the present it has been found sufficient to add the star C.G.A. Cluster Catalogue, No. 121, there given as mag.=8.0 red. I have used this magnitude; the colour is about 8 on Chandler's scale. The other comparison star used in the following observations was Gilliss 1332, mag. 7.60; colour, full yellow = 4 on Chandler's scale.

Both of these stars are most conveniently situated with reference to η Argûs, which is between them in position, and also at present between them in magnitude and colour.

With the 7-in. Merz equatorial :—

1899 June 10 mag. = 7.6	
11	7.8 colour = 8.
13	7.75.
18	7.7 colour = 6.
1899.5	mag. 7.71 colour 7.

To compare we have :—

1897.2	7.60	See, A.J. 399, p. 119.
1896.4	7.58	Innes, M.N. lvii. p. 115.
1886.2	7.60	Finlay, „ xlv. p. 340.

All in U.A. scale.

Royal Observatory, Cape of Good Hope,
1899 June 20.

Tempel's Comet (1873 II-c 1899), observed at Grahamstown.
By Major L. A. Eddie.

1899, August 15.—Comet well seen, though Moon too bright for detecting much physical structure. Head sharply defined on preceding edge, narrow in anterior portion, spreading out immediately at a wide angle, and very much diffused posteriorly. Condensation in central portion of head. Colour pale white, but moonlight too bright to detect any particular tint. This comet did not appear fluffy, like Swift's comet observed at my observatory in March last, but with a sharp outline on advancing edge. Though faint, stood power of 100 well.

August 17.—Moon very bright, and atmosphere hazy, so comet only dimly visible.

August 18.—Comet nearly eclipsed by moonlight, though could be traced as well spread out, with central portion fairly condensed. Colour very pale bluish white.

August 24.—Early evening, dark. Comet well seen in finder. In $9\frac{1}{4}$ -inch reflector nucleus globular in form, and well condensed, of pale white colour, about 2' in diameter, and surrounded by wide but very rare coma. A broad, though extremely faint, tail, could be traced to about 16'.

Spectroscope gave dim continuous spectrum, with brighter concentration in one portion, but no bands detected.

August 25.—Comet well seen on dark background. Cometic envelopes, though faint, well defined, with two dark intervals in preceding portion, fairly conspicuous condensed nucleus, with dark rift behind, and broad, faint tail about 16' in length. No bands detectable with spectroscope.

August 28.—Comet already much fainter. Detail not well seen, but considerable surrounding coma still visible. Stellar point in condensed portion suspected. Comet subsequently observed on August 29, 31, September 1, 2, 5, 7; but no great changes detectable, only getting gradually fainter, though condensed nucleus and wide spread surrounding coma in hyperbolic form still noticeable; dark rift in faint tail generally seen, coma usually showed a very streaky appearance.

Approximate Positions.

	C. U. T.			R. A.			S. Dec.			C. U. T.			R. A.			S. Dec.	
	h	m	s	h	m	s	°	'		h	m	s	h	m	s	°	'
Aug. 15	11	0		21	12		31	4		Aug. 29	8	0	21	29		35	0
17	10	0		21	13 $\frac{1}{2}$		31	33		31	8	0	21	31 $\frac{3}{4}$		35	16
18	10	0		21	14 $\frac{1}{2}$		32	12		Sept 1	8	0	21	33		35	24
24	10	0		21	22 $\frac{1}{2}$		33	54		2	9	30	21	34 $\frac{1}{2}$		35	32
25	9	15		21	23 $\frac{3}{4}$		34	21		5	8	30	21	38 $\frac{1}{2}$		35	49
28	8	30		21	27 $\frac{1}{2}$		34	51		7	8	15	21	40		36	0

Grahamstown :

Sept. 9, 1899.

Observations of Jupiter in 1899. By W. F. Denning.

Between 1899 February and September (but chiefly in the months June to September) I obtained 668 transit times of various markings on *Jupiter*. All the observations were effected by the help of a 10-inch With-Browning reflector and one of Steinheil's monocentric oculars having a power of 312. It is not intended to give the details of the observations,* but simply

* This is rendered unnecessary by the fact that Mr. A. S. Williams of West Brighton is investigating the motion of the equatorial current, while the Rev. T. E. R. Phillips, of Yeovil, is discussing all the observations of spots in the extra-equatorial currents.

a condensed summary of the principal results, as they may be useful in this form to compare with my similar results for 1898 (*Monthly Notices*, lviii. p. 480 *et seq.*).

Equatorial Spots.—Twenty-seven white and dark spots situated on the N. edge of the great S. equatorial belt gave a mean period of

$$9^{\text{h}} 50^{\text{m}} 24^{\text{s}}.6.$$

This is one second greater than the rate derived from 23 similar markings observed here in 1898, so that the equatorial current (or at any rate that section of it contiguous to the S. belt) has slightly moderated its velocity during the last twelve months. There were large differences (as in 1898) in the periods found from the individual spots in this latitude. The maximum period was $9^{\text{h}} 50^{\text{m}} 35^{\text{s}}$, the minimum $9^{\text{h}} 50^{\text{m}} 18^{\text{s}}$. The average number of observations of each of the spots was 11, and the number of rotations 255.

North Tropical Spots.—Sixteen white and dark spots on the north side of the northern equatorial belt indicated a mean period of

$$9^{\text{h}} 55^{\text{m}} 28^{\text{s}}.8;$$

but in this latitude also the various objects gave very discordant rates. Three of them moved with remarkable swiftness, and had a mean period of $9^{\text{h}} 55^{\text{m}} 16^{\text{s}}.4$, while 13 others gave $9^{\text{h}} 55^{\text{m}} 32^{\text{s}}.5$. The average number of observations for each marking was 7, and the rotations performed 153. In 1898, three dark spots in this current gave a period of $9^{\text{h}} 55^{\text{m}} 26^{\text{s}}.3$.

Markings in Southern Hemisphere.—Three spots in latitude about 25° to 30° S. had a mean period of

$$9^{\text{h}} 55^{\text{m}} 18^{\text{s}}.6.$$

Two other objects further south, in about lat. 40° to 50° S., moved more rapidly, the rate being

$$9^{\text{h}} 55^{\text{m}} 9^{\text{s}}.2.$$

Markings in Northern Hemisphere.—Two well-defined dark spots were watched in lat. 25° to 30° N., and they exhibited a considerable difference of motion. One, which was nearly in the same longitude as the red spot in 1899 March, indicated a period of

$$9^{\text{h}} 55^{\text{m}} 29^{\text{s}}.8.$$

The other moved more slowly than any other object on the disc of the planet, its rate being

$$9^{\text{h}} 55^{\text{m}} 53^{\text{s}}.5.$$

The Red Spot and Hollow in the S. Hemisphere.—The spot continued exceedingly faint in 1899, but on a night of good definition its complete elliptical outline could be distinctly perceived except perhaps its extreme southern side, where it appeared to blend with the dusky south temperate belt. The *f* end of the spot was more distinct than the *p* end, and this has been the common experience in recent years. The hollow in the great southern equatorial belt seems to follow the spot by 2 or 3 minutes; but this appearance is due to a difference in the form of the shoulders of the hollow. The *p* side is flatter than the *f* side, hence the spot seems naturally to lean towards the latter. As the hollow in the belt is a very conspicuous feature and exhibits precisely the same rotation period as the red spot, and as the latter is often partly or wholly obliterated in bad definition, I obtained transits of the centre of the former object as the times may be regarded as practically identical with the times of central transit of the red spot. Between February and September 35 transits were taken, and the first and last of these, as under, appear to accurately represent the position of the object on the two dates:—

		^h	^m	^s
1899 February	2	18	39	29.5
September	16	5	41	36.5

545 rotations were performed in this interval, and the mean period was

$$9^{\text{h}} 55^{\text{m}} 41^{\text{s}}.9.$$

This is one-tenth of a second in excess of that deduced from my observations between 1898 March and July. But there is no doubt that, after 1898 July, the spot exhibited a marked acceleration of motion, and it was unfortunate that, during the autumnal months, *Jupiter* was too near to the Sun to permit of the continued observation of this feature. In 1899 February, when the planet came favourably into view, the hollow arrived on the central meridian fully 5 minutes before its computed time. In fact the rotation period of the object varied as follows:—

		^h	^m	^s
1898 March to July	...	9	55	41.8
1898 August to 1899 April		9	55	41.2
1899 May to September	...	9	55	42.0

That this change of rate actually occurred is beyond question, for it is well corroborated by the evidence of other observers.

Summarising my results for 1899, the figures are :—

Objects.		Rotation Period.		
		h	m	s
27	White and dark equatorial spots ...	9	50	24·6
16	North tropical spots lat. 12°–15° N.	9	55	28·8
3	Spots in S. hemisphere lat. 25°–30° S.	9	55	18·6
2	„ „ lat. 40°–50° S.	9	55	9·2
1	„ N. „ lat. 25°–30° N.	9	55	29·8
1	„ „ „ „ „	9	55	53·5
	Red-spot-hollow in S. hemisphere ...	9	55	41·9

Bristol: 1899 September 21.

Early History of the Great Red Spot on Jupiter.

By W. F. Denning.

In the Supplementary Number of the *Monthly Notices*, 1898, I gave some particulars of observations of objects apparently identical with the great red spot on *Jupiter*, as their positions and rate of motion were found consistent with one another. The varying period of rotation was traced back to Gledhill's first accurate recognition of the ellipse on 1869 November 14. Since this paper was published I have collected many additional observations and drawings of the hollow in the great southern equatorial belt, or of the ellipse, extending back to 1831 September 5. Though the red spot or its modification, the ellipse, appears to be quite wanting from many of the drawings, yet a very well marked hollow in the south equatorial belt may be safely presumed to accurately indicate its position, as it has done in several recent years. Before 1857 the oval spot appears to have been indistinguishable, and was probably covered with material outlying it above the surface of *Jupiter*. The Rev. W. R. Dawes in 1857 figured an object similar to it in *Monthly Notices*, vol. xviii. p. 50, and Sir William Huggins has sent me his drawings (very excellent copies of which were kindly made for this purpose by Lady Huggins) from 1858 December to 1860 April, and in many of these a well-defined ellipse with dark ends is shown in the south hemisphere. I am also much indebted to Mr. A. Stanley Williams and to Mr. W. H. Wesley for copies of many of Schwabe's drawings of *Jupiter* between 1831 and 1856. These were taken from the MS. volumes of Schwabe's observations in the possession of the R.A.S. Mr. J. Baxendell, of Southport, has also sent me some copies of papers published by his father, the late Joseph Baxendell, F.R.A.S., which contain some well-executed delineations of the hollow in the south equatorial belt (see *Monthly Notices*, vol. xx. p. 244). In the *Memoirs of the*

Lit. and Phil. Society of Manchester, session 1859-60, Mr. Baxendell gave eight observed transits of a dark spot in about $28\frac{1}{2}^{\circ}$ * south latitude, visible in the months from 1859 January to April. He determined its mean rotation period as $9^h 55^m 37^s.812$, and there is no doubt whatever from a comparison with Sir William Huggins's drawings at about the same period, that this spot was really the dark following end of the ellipse. If twenty-seven minutes ($=16\frac{1}{2}^{\circ}$ of longitude) are deducted from Mr. Baxendell's transit times they agree as nearly as possible with the estimated times of transit of the middle of the ellipse figured on many occasions by Sir William Huggins. In the following table this deduction has therefore been made in regard to the eight observations alluded to, which have been marked with an asterisk to distinguish them from the other transit times, all of which are dependent upon estimations from the position of the object east or west of the central meridian on drawings.

The transit times, being nearly all adopted from sketches which do not always represent the exact position of the spot or hollow at the minute the sketches were dated, may be sometimes erroneous to the extent of as much as 20 minutes, or possibly, in an exceptional case, 30 minutes. But even a misplacement of this large amount does not seriously impair the value of the rotation period when it is deduced from several years of observation. Thus, an error of 30 minutes would make one second difference in the period of rotation based on two years' observation, 0.68 second on 3 years, 0.54 on 4 years, and 0.41 on 5 years. This is, however, an extreme case, and I have endeavoured to avoid so large an error by testing and correcting the transits employed, by others, whenever practicable, obtained at nearly the same epoch.

Observations of the Hollow in the Great Southern Equatorial Belt or of the Red Ellipse in the South Hemisphere of Jupiter, 1831 September 5 to 1869 November 14.

Observer.	Year, month, and day.	Estimated transit time.	G.M.T. of sketch.	Position of object rela- tively to the
				O.M.
H. Schwabe	1831 Sept. 5	$8^h 21^m$	$8^h 56^m$	21° W.
"	19	$9^h 51^m$	$9^h 11^m$	24° E.
"	Nov. 5	$3^h 46^m$	$3^h 56^m$	6° W.
"	1832 Oct. 9	$7^h 31^m$	$8^h 11^m$	24° W.

* This is several degrees south of the position of the red spot in recent years, but it by no means negatives the assumption of identity. The spot varies in latitude (possibly at regular periods) as well as in longitude. Professor G. W. Hough has made a series of measures of the position of the red spot during the last twenty years with a refractor of $18\frac{1}{2}$ -inch aperture, and says the object "has drifted in latitude, the total displacement being $2''.1$ of arc." The maximum south latitude was in 1886, when the spot was $7''.41$ distant from the equator, and the minimum in 1892, when the distance was $5''.32$. This represents a difference in latitude of about 7° .

Observer.	Year, month, and day.	Estimated transit time.	G.M.T. of sketch.	Position of object rela- tively to the O.M.
		h m	h m	
H. Schwabe	1840 Apr. 26	8 51	9 26	21° W.
"	1845 Dec. 2	5 36	3 56	61 E.
"	1850 Feb. 26	6 31	6 41	6 W.
"	1851 May 10	7 26	7 3	14 E.
"	1852 June 25	7 1	7 11	6 W.
"	July 2	...	7 41	25 E.
"	1855 Sept. 22	3 51	5 56	75 W.
"	29	4 50	5 18	17 W.
"	Oct. 23	4 11	4 41	18 W.
"	Nov. 9	4 15	3 56	11½ E.
"	21	...	4½ ^h -6½ ^h	66 W.
"	26	2 56	3 41	27 W.
"	1856 Aug. 31	8 11	9 11	36 W.
"	Sept. 7	8 56	9 11	9 W.
"	9	10 41	9 11	54 E.
"	Oct. 20	9 11	8 11	36 E.
*Rev. W. R. Dawes	1857 Nov. 27	7 20	8 10	30 W.
†Sir W. Huggins	1858 Dec. 29	10 20	10 50	18 W.
"	1859 Jan. 15	9 26	9 40	8½ W.
‡J. Baxendell	23	6 0	...	...
"	Feb. 6	7 36	...	...
Sir W. Huggins	10	10 50	10 45	3 E.
J. Baxendell	11	6 38	...	...
Sir W. Huggins	13	8 15	8 45	18 W.
"	23	6 20	6 40	12 W.
J. Baxendell	23	6 38	...	...
"	Mar. 7	6 28	...	...
"	Apr. 7	7 0	...	...
"	9	8 34	...	...
"	21	8 35	...	...

* The drawings by Dawes in 1857 are in *Monthly Notices*, vol. xviii. p. 50. On December 5 of the year named the *f* end of the ellipse is shown just passing off west limb, but the drawing was probably made at 6^h 30^m instead of 7^h 30^m as stated.

† *Observatory*, vol. v. p. 49.

‡ The eight transit-times due to Mr. Baxendell in 1859 were actually observed by him.

Observer.	Year, month, and day.	Estimated transit time.	G.M.T. of sketch.		Position of object rela- tively to the C.M.
			h m	h m	
*J. W. Long	1860 Feb. 29	7 55	7 45		6° E.
†Sir W. Huggins	Mar. 2	9 40	9 0		24 E.
‡J. Baxendell	2	9 45	9 24		12½ E.
Capt. W. Noble	2	10 10	10 2		5 E.
‡J. Baxendell	5	7 32	7 18		8½ E.
Capt. W. S. Jacob	12	8 10	7 40		18 E.
Capt. W. Noble	1863 Apr. 28	9 40	9 40		on C.M.
§N. E. Green	May 7	12 10	11 30		24 E.
Capt. W. Noble	7	12 20	10 55		51½ E.
"	17	10 25	9 35		30 E.
T. W. Backhouse	1864 July 19	8 35	9 20		27 W.
"	1867 Aug. 30	10 45	10 10		21 E.
Capt. W. Noble	Sept. 13	12 10	11 54		9½ E.
J. Gledhill	1869 Nov. 14	10 50	..		...

There can be no doubt that, in addition to this, much other evidence of a corroborative nature might be obtained by an exhaustive search amongst old records of Jovian observations. But the above are amply sufficient for the purpose of deriving a trustworthy rotation period for a considerable part of the whole interval. Additional data would, however, be useful for the periods from 1831 to 1850, and 1860 to 1869. Mr. A. S. Williams informs me that Schmidt obtained 300 or 400 drawings of *Jupiter* between 1843 and 1880, and if these could be consulted they would undoubtedly supply much reliable evidence on the early history of the red spot and its surroundings.

From a selection of some of the best observations in the foregoing summary I have worked out the rate of rotation of the spot or hollow in the south equatorial belt, in various years, as follows :—

* The drawing appears in *Monthly Notices*, vol. xx. p. 244.

† *Observatory*, vol. v. p. 49, but the date is there erroneously given as 1858 March 2.

‡ *Monthly Notices*, vol. xx. p. 244. Capt. Jacob's drawing of 1860 March 12 will also be found here.

§ *Astronomical Register*, 1872, fig. 4.

Hollow in S belt, or ellipse. Rotation Period 1831 Sept. 5 to 1869 Nov. 14.*

Observers.	Dates of the Observations.	Interval.	Rotations.	Corrected Rotation Period.	Daily Rate.
		d h m		h m s	o
H. Schwabe ...	1831 Sept. 5 8 21	399 23 10	967	9 55 32.5	870.47
" ...	1832 Oct. 9 7 31	2756 1 20	6663	9 55 34.5	870.42
" ...	1840 Apr. 26 8 51	2045 20 45	4946	9 55 35.2	870.40
" ...	1845 Dec. 2 5 36	1547 0 55	3740	9 55 35.4	870.40
" ...	1850 Feb. 26 6 31	438 0 55	1059	9 55 35.6	870.39
" ...	1851 May 10 7 26	411 23 35	996	9 55 35.3	870.40
" ...	1852 June 25 7 1	1183 20 50	2862	9 55 36.1	870.38
" ...	1855 Sept. 22 3 51	353 6 50	854	9 55 37.3	870.35
" ...	1856 Sept. 9 10 41	443 20 39	1073	9 55 37.6	870.34
Rev. W. R. Dawes	1857 Nov. 27 7 20	397 3 0	960	9 55 37.4	870.35
Sir W. Huggins	1858 Dec. 29 10 20				
Sir W. Huggins	1860 † Mar. 2 9 52	428 23 32	1037	9 55 38.4	870.32
Capt. W. Noble					
J. Baxendell ...		1171 0 33	2831	9 55 35.5	870.40
Capt. W. Noble	1863 May 17 10 25	1580 1 45	3820	9 55 34.5	870.42
"	1867 Sept. 13 12 10	792 22 40	1917	9 55 34.5	870.42
J. Gledhill ...	1869 Nov. 14 10 50				
H. Schwabe ...	1831 Sept. 5 8 21	13950 2 29 337.28 ‡		9 55 35.3	870.40
J. Gledhill ...	1869 Nov. 14 10 50				

For the interval elapsed since 1869 November 14 to the last observation obtained at Bristol, I find the following:—

		h m	d h m R.	h m s	o
J. Gledhill ...	1869 Nov. 14 10 50		10897 18 51	26346	9 55 37.9
W. F. Denning	1899 Sept. 16 5 41				870.33

For the entire period of 68 years since 1831:—

H. Schwabe ...	1831 Sept. 5 8 21	24847 21 20 600.74	9 55 36.4	870.37
W. F. Denning	1899 Sept. 16 5 41			

* For a similar table to this, carrying the observations from 1869 to 1898, see *Monthly Notices*, lviii. p. 491.

† In this case I have taken the mean transit time derived from three good drawings made on the same evening, and all representing the hollow as a very conspicuous feature.

‡ Three more rotations than the total of the number included in the periods above. This is because Jupiter apparently loses one rotation during a revolution round the Sun, and the rotations given for the shorter periods are really the number observed. This in every case is less by a fractional part than the actual total. Thus, in the second period in the table between 1832 and 1840 the number of rotations observed was 6663, but the actual number performed by the planet was 6663 and two-thirds.

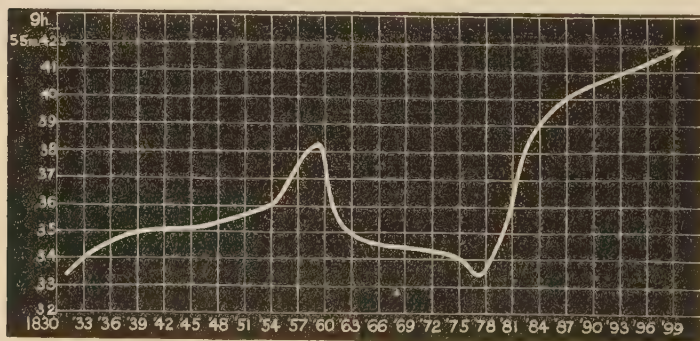
For several of the longer periods, where no intervening observations afford a criterion, the number of rotation periods has necessarily been assumed. It may be thought, therefore, that the precise number employed is open to doubt; but there is little evidence to support this view, as the resulting rotation periods all show a consistent agreement, and there are a few observations near the beginning or closing of several of the periods which prove that the figures are correct. Moreover, if one rotation too many or too little were adopted, it would throw the periods out considerably, and indicate some extraordinary fluctuations in the rate of the spot. Thus, for the longest period (embracing $7\frac{1}{2}$ years) in the table, the assumed number of rotations is 6663. This number gives a period presenting a most suggestive agreement with the others. If 6662 rotations had been adopted, the resulting period would have been $9^h 55^m 40^s$, and if 6664, $9^h 55^m 29^s$. These figures are discordant with the rates exhibited during the periods preceding and following. But they are not altogether impossible in view of the irregularities which have been occasionally observed in the motion of the spot. For the smaller periods in the table the number of rotations may be safely regarded as correct, as any other number would give an abnormal period. Still, it is hoped that to ensure absolute confidence in the results obtained, some additional observations will be found to fill up the longer intervals. In consulting old records, references are occasionally met with which undoubtedly refer to the red spot or the accompanying hollow in the southern belt. Thus, Dr. O. Lohse, of Bothkamp, quotes the following observation by the Bonds at Harvard College Observatory. 'On February 3, 1848, at $9^h 30^m$ M.S.T. (Camb.) three belts only were seen. The broad one lying a little south of the equator had no longer its sides parallel, as on January 28, but a deep hollow on the south edge, reaching nearly across on the *p.* side.'

Taking the average rotation periods in the foregoing table (1831 to 1869), and those in my previous paper on the same subject (*Monthly Notices*, vol. lviii. p. 491), the smoothed rate in successive years appears to have been as follows:—

Year.	h	m	s	Year.	h	m	s	Year.	h	m	s
1831—	9	55	33·3	1841—	9	55	35·0	1851—	9	55	35·7
1832—		33	6	1842—		35	1	1852—		35	8
1833—		33	9	1843—		35	1	1853—		35	9
1834—		34	1	1844—		35	2	1854—		36	0
1835—		34	3	1845—		35	2	1855—		36	1
1836—		34	5	1846—		35	3	1856—		36	7
1837—		34	7	1847—		35	3	1857—		37	5
1838—		34	8	1848—		35	4	1858—		38	0
1839—		34	9	1849—		35	5	1859—		38	3
1840—		35	0	1850—		35	6	1860—		37	1

Year. h m s	Year. h m s	Year. h m s
1861—9 55 35·9	1874—9 55 34·2	1887—9 55 40·1
1862— 35·3	1875— 34·0	1888— 40·2
1863— 35·0	1876— 33·7	1889— 40·4
1864— 34·8	1877— 33·4	1890— 40·5
1865— 34·7	1878— 33·7	1891— 40·6
1866— 34·6	1879— 34·1	1892— 40·8
1867— 34·5	1880— 35·2	1893— 40·9
1868— 34·5	1881— 36·3	1894— 41·0
1869— 34·5	1882— 37·3	1895— 41·1
1870— 34·4	1883— 38·2	1896— 41·3
1871— 34·4	1884— 39·0	1897— 41·5
1872— 34·3	1885— 39·6	1898— 41·7
1873— 34·3	1886— 39·9	1899— 41·9

The rotation period increased gradually and regularly from about $9^{\text{h}} 55^{\text{m}} 33^{\text{s}}$ in 1831 to about $9^{\text{h}} 55^{\text{m}} 38^{\text{s}}$ in 1859, when it rapidly decreased to about $9^{\text{h}} 55^{\text{m}} 36^{\text{s}}$ in 1861. Then the decrease became very gradual, and during the fifteen years from 1865 to 1879 inclusive it seems to have varied little from $9^{\text{h}} 55^{\text{m}} 34^{\text{s}}\cdot 3$. In 1880 and three following years the period increased rapidly, so that in 1884 it was $9^{\text{h}} 55^{\text{m}} 39^{\text{s}}$. During the next fifteen years the increase was continued, but very slowly, so that in 1899 the period was $9^{\text{h}} 55^{\text{m}} 41^{\text{s}}\cdot 9$. A diagram will, however, exhibit the variations which have occurred more strikingly than any description :—



Variation in Rotation period of the Red Spot and hollow in S. belt during the 68 years from 1831 to 1899.

It has often been suggested that the great red spot of recent years may be identical with the large spot discovered on *Jupiter* in 1664 by Robert Hooke and seen in 1665, and following years by J. D. Cassini. The *Phil. Trans.* vol. i. p. 3 (abridgment) contains the following paragraph concerning the spot :—

"The ingenious Dr. Hooke did some months since intimate to a friend of his that he had, with an excellent 12-feet telescope, observed, some days before he then spoke of it (viz., on 1664 May 9 O.S.), about nine o'clock at night, a spot in the largest of the three obscure belts of *Jupiter*; and that, observing it from time to time, he found that, within two hours after, the said spot had moved east to west about half the length of the diameter. It is situated in the northern part of the southern belt. Its diameter is one-tenth of *Jupiter*; its centre, when nearest, is distant from that of *Jupiter* about one-third of the semi-diameter of the planet."

In the same volume of the *Phil. Trans.*, p. 60, appears the following:—

"Hooke's Permanent Spot on Jupiter."

"M. Cassini, after many observations during the summer of 1665, found that the period of its apparent rotation is $9^h 56^m$. He continued to observe this spot till the beginning of 1666, when *Jupiter* approached to the beams of the Sun; but after he had got out of them it was difficult to be discerned. But, 1672 January 19, N.S., observing *Jupiter* at $4\frac{3}{4}$ hours in the morning, he perceived in the same place of his disc the figure of the same spot adhering to the same southern belt. It had already gone over the half of this belt, and he saw it advance gradually towards the western limb, to which it seemed very near at $6\frac{1}{4}$ hours. By the celerity of its motion near the centre, and by the place when he had begun to see it, he judged it might have been in the middle of the belt at 4 hours and 35 minutes in the morning. And as he set about making ephemerides of its motion for 1672, he perceived that in those he made for 1666 this spot had been in the middle of *Jupiter* the same day, viz. January 19, at the same hour, so that in six years, of which one is a bissextile, it is found to have in respect of the Earth at least 5294 revolutions of $9^h 55^m 58^s$, one revolution with another, and at most 5295 revolutions of $9^h 55^m 51^s$, forasmuch as he was assured of the preciseness of one mean revolution to one-eighth of a minute. Till that time he never observed an immediate return of this spot after $9^h 56^m$, because that after the appearing of the spot *Jupiter* had not continued long enough above the horizon to observe him with due distinctness. But the night after March 1, at $7\frac{1}{2}$ hours in the evening, he saw this spot in the middle of the belt; and at $5^h 26^m$ in the following morning he saw it again return precisely to the same place." . . . "The next day" (vol. i. p. 706) "he made a report of these observations to the Royal Academy of Sciences, and predicted that the spot would arrive again at the midst of the belt on March 3 at 8 minutes after 9 o'clock; whereupon the assembly deputed M. Biot and M. Mariotte to be present at the observatory, who, being come to the Royal Observatory, began to see, at 4^m after 8 o'clock, the spot, already somewhat removed from the eastern limb, but yet

obscure and small. At 47^m after 8 o'clock they saw it very distinctly advancing towards the middle of the belt. From 5^m 40^s after 9 o'clock until 8^m after 9 o'clock they saw it in the midst of the belt. At 15^m after 9 o'clock it had passed the middle, and was come nearer to the western limb. And a little after, the heavens being overcast, they could then observe no further."

The spot appears to have been intermittently visible, for we find references to it as follow :—

1664 May 19 (N.S.) Discovered by Hooke.

1665 to 1667. Frequently seen by Cassini, but faint, in 1667.

1672 January 19. Re-detected by Cassini, and followed to end of 1674.

1677. Seen, but disappeared in the same year.

1685 March. Re-observed, and continued in view until 1687 October.

1690. Seen for a short time.

1691. Reappeared, but became invisible again in 1693.

1694. Seen.

1708. Seen.

1713. Re-observed by Maraldi, but finally disappeared after this year.

It would be interesting to consult the early volumes of the *Académie des Sciences* and discuss the observations. The rotation period might thus be determined, together with its changes of rate, for the fifty years from 1664 to 1713. Derham says that Cassini's observations are to be found in *Memoires de Mathem. et Phisique*, 1692 January.

From the date of Hooke's discovery of the spot on 1664 March 19 (N.S.) to Cassini's observation of the same object on 1666 January 19 (N.S.) I find the object performed 1472 rotations, with a corrected mean period of 9^h 55^m 58^s.7. Between Cassini's observation in 1666 January and others which he effected in 1672 January and March the motion appears to have increased, for from 5402 rotations the period was 9^h 55^m 54^s.2. If during the nine years from 1664 to 1672 inclusive the motion increased in a gradual manner, the annual values for the rotation period were probably as under :—

	h	m	s		h	m	s
1664	9	55	59	1669	9	55	54
1665			58	1670			53
1666			57	1671			52
1667			56	1672			51
1668			55				

Cassini says that between 1666 January 19, 4.35 A.M. and the same date and hour in 1672, the planet made at least 5294 rota-

tions, or at most 5295. The real number appears to have been 5294.

In 1713, according to J. P. Maraldi, the rate was $9^h 56^m$, so that the maxima occurred in about 1664 and 1713. If we adopt a cycle of $48\frac{1}{2}$ years as representing the changes, then maxima are also indicated for 1761, 1810, 1858, and 1907. This conforms very nearly with the slow rate observed for the red spot in 1859. It is also noteworthy that a period of about forty-eight years corresponds with the rapid motion of the spot exhibited in about 1831 (perhaps the minimum period really occurred in 1829, for which we have no observations), and 1877. These, however, are merely suggestions from insufficient data, the more complete investigation of old records would probably lead to more definite and certain conclusions.

In 1773, Jacques de Sylvabelle determined the period of a spot on *Jupiter* as $9^h 56^m$, but I am not aware whether this object offered any resemblance either in its form or position to Hooke's spot of 1664, or to the red spot of our own time. If the latter can be assumed to be identical with Hooke's spot of 1664 May 19, and the mean rate of rotation to have been $9^h 55^m 40^s$ during the long interval of $235\frac{1}{2}$ years to 1899 September 16, then the planet will have rotated 207,780 times since the spot was first discovered. The ancient marking is often called "Cassini's spot," though Cassini was certainly anticipated by Hooke, but the latter seems to have curiously neglected this feature and to have scarcely thought it worth mention. On the other hand, Cassini followed it with great perseverance, and derived some interesting conclusions from its apparition; to him, therefore, belongs the most credit, and his name will always be closely associated with this interesting object.

In concluding, it may be mentioned that the supposed invisibility of the red spot in 1877 has sometimes been alluded to as a curious circumstance. When in opposition in June of that year the planet had a declination 23° S. of the equator, so it cannot be wondered at that this marking escaped observation in England. It was, however, seen at Sydney, N.S.W., by Mr. H. C. Russell, who writes me that, though during the summer of 1877 *Jupiter* was somewhat neglected in favour of *Mars*, the red spot was often observed. Its figure became so familiar that it was termed the "pink fish," it being somewhat fish shaped, the *p* end being round and the *f* end tapering. The observers having noticed its constancy in 1876 and 1877, regarded it as a permanent marking on the planet. Mr. Russell quotes one of his observations to the effect that on 1877 August 26, at 8 P.M. (local time), the "pink fish" was just passing off the planet's limb. In 1876 the spot was frequently seen, and appears on many of the drawings made at the Sydney Observatory in May, June, and July of that year. From Mr. Russell's descriptions of the position of the object relatively to the central meridian in the various drawings alluded to, its times of transit must have been approximately as follows:

							Transit G.M.T.
							h m
1876 May	31	...	...	...	...	...	0 25
June	2	...	...	...	...	...	1 20
	7	...	...	...	...	...	0 25
	7	...	...	...	...	...	20 15
	9	...	...	...	...	...	21 47
	19	...	...	...	...	...	20 5
	29	...	...	...	...	...	18 35
July	1	...	...	...	...	...	0 5
	3	...	...	...	...	...	1 50

These times are fairly consistent with each other (considering the nature of the estimates), except the first one on May 31, which seems more than thirty minutes late.

Bristol: 1899 September 21.

Errata.

Monthly Notices, lviii. p. 484. The number of rotations for spot No. 1 should be 87 instead of 101, and for spots Nos. 12 and 13, 161 instead of 154.

On p. 491 the number of rotations between 1869 Nov. 14 and 1898 July 30 is stated as 25,346. This is the observed number; the actual number performed was 25,348 and about one-third.

Note on the Motion of Jupiter's Red Spot. By C. Flammarion.

The slackening motion of the spot has proceeded in fair accordance with the forecast given in Mr. Crommelin's Ephemeris to the effect that it would "follow the zero-meridian of System II. by about 52^m at the beginning of this Ephemeris (1898 December 10), and about 59^m at the end of it" (1899 September 18).

A considerable number of transits of the Red Spot region over the central meridian of *Jupiter* have been secured at Juvisy during the present apparition. Owing, however, to the extreme attenuation of the spot's intensity, and to the concomitant difficulty of the observations, the estimated times of transit do not refer to the centre of the red spot itself, but to that of the cavity in which it is located.

On 1899 May 30 the following transits were noted by M. Antoniadi:—

	h m.
Passage of <i>p</i> shoulder	9 36 G.M.T.
Passage of centre of cavity	10 9.5 (Plate I, Fig. 1).
Passage of <i>f</i> shoulder	10 43

$$\lambda = 34^{\circ}.1.$$

$$\phi = -3^{\circ}.1.$$

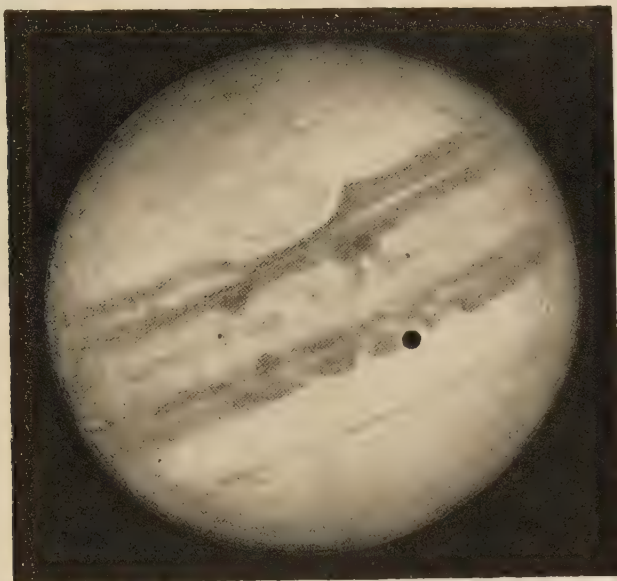


FIG. 1.—1899 MAY 30^d 10^h 9^m 5^s G.M.T.
(E. M. ANTONIADL.)

$$\lambda = 23^{\circ}.6.$$

$$\phi = -3^{\circ}.1.$$

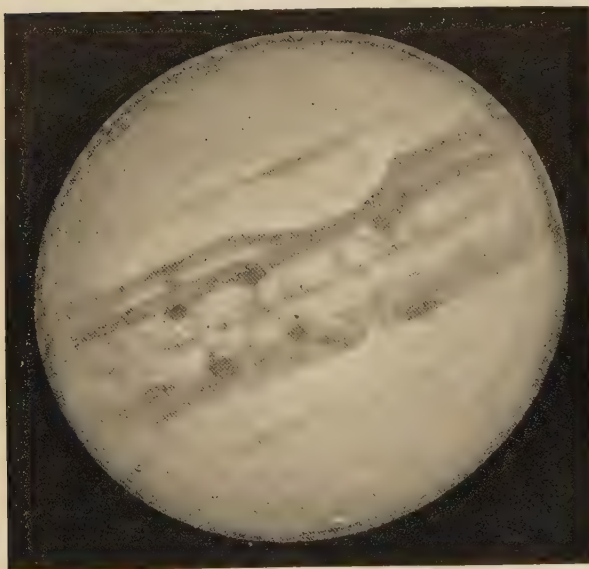


FIG. 2.—1899 JUNE 4^d 9^h 0^m.
(C. FLAMMARION.)

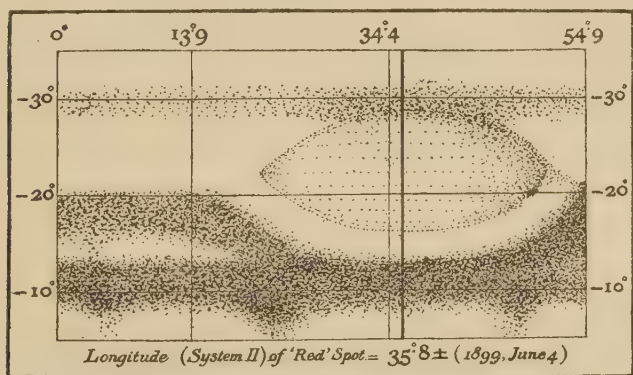
As the zero-meridian of System II. was central at $9^h 13^m.0$, it follows that the centre of the bay was $56^m.5$ late on May 30, which corresponds to $\lambda = 34^\circ.1$.

Five days later, on June 4, I was enabled to make the following observations:—

	h	m	
Passage of <i>p</i> shoulder	8	44	G.M.T.
Passage of centre of cavity	9	18	
Passage of <i>f</i> shoulder	9	52	

The zero-meridian being central at $8^h 21^m.1$ on June 4, we have for the longitude of the middle of the bay the value of $56^m.9 = 34^\circ.4$. Fig. 2 of the accompanying plate (plate 10) was taken some eighteen minutes before the passage of the Red Spot.

The observations of Mr. Denning* and Rev. T. E. R. Phillips have shown that the spot is not quite central in the great bay, being somewhat nearer to the *f* elbow. Now, as our recent impressions confirm this view, $59^m \pm = 35^\circ.8 \pm$ might be considered as a more probable value of the spot's longitude on June 4 than $56^m.9 = 34^\circ.4$. The subjoined map of the Red Spot region resumes my impressions at the latter date.



Inasmuch as *Jupiter* is showing us at the present apparition his south pole, the belts are not straight, but curved, being concave to the south, as drawn by Mr. Stanley Williams in his *Zenographical Fragments*, twelve years ago. I should also like to confirm Mr. Williams's statement that "both belts are of a moderately deep red colour, and are [now] nearly equally red, though the south equatorial belt usually appears distinctly a little redder than the north equatorial belt."[†]

* *Monthly Notices*, vol. lviii. No. 9.

† *Ibid.* vol. lix. No. 7. The belts appeared to me fainter at this apparition than during the last few years.

Further Notes on Saturn's "Crape" Ring. By E. M. Antoniadi.

The paper on pp. 498-501 has shown the hypothesis of a dark ring round *Saturn* to be unnecessary; indeed, the phenomena seem only explicable by the assumption of a bright ring. We thus reach the generalisation that the albedo of the individual particles is very likely the same in *all* parts of the ring system, and that brightness here is a function of aggregation.

The remarkable appearances which were observed by Dawes half a century ago, and which led him to consider the figure generating this ring to be "somewhat wedge-shaped," have been shown to be rational consequences of the interpretation in question; but the differences between the heights of the Sun and Earth above the plane of the ring have not been ascribed at first by the writer to their ordinary and most effective cause, which is the motion of the Earth in her orbit.

When Dawes wrote that the projection of the dark ring at its minor axis was "considerably narrower than accords with its breadth at the major axis," the difference in altitude of the Sun and Earth above the ring was very considerable, as will be seen from the following data, taken from the *Nautical Almanac* of 1850 and 1851, and for which the writer is indebted to the kindness of M. Fraissinet, Secretary to the National Observatory, Paris. The height of the Sun above the plane of the ring is here designed by *a*, that of the Earth by *b*, while Δ stands for the difference of these two values:—

Date.	<i>a</i>	<i>b</i>	Δ
1850 November 17	$11^{\circ} 56'0''$ S	$10^{\circ} 5'9''$ S	$1^{\circ} 50'1''$
" December 27	$12^{\circ} 30'1''$	$9^{\circ} 57'2''$	$2^{\circ} 32'9''$
1851 January 1	$12^{\circ} 34'0''$	$10^{\circ} 1'1''$	$2^{\circ} 32'9''$
" February 10	$13^{\circ} 7'8''$	$11^{\circ} 11'4''$	$1^{\circ} 56'4''$

A letter of Dawes', dated 1852 November 29,* mentions that "in the beginning of 1851 the difference" [narrowness of "dark" ring across the globe] "appeared much greater than it now does." These words give us an opportunity to submit our theory to a crucial test, for, if correct, it would necessitate a smaller value of Δ for 1852 November than for 1850 December-1851 January. Checking our deduction by the ephemeris given in the *Nautical Almanac*, we find it verified to the letter:—

Date.	<i>a</i>	<i>b</i>	Δ
1852 August 28	$20^{\circ} 19'2''$ S	$21^{\circ} 52'2''$ S	$-1^{\circ} 33'0''$
" October 7	$20^{\circ} 45'4''$	$21^{\circ} 26'0''$	$-0^{\circ} 40'6''$
" November 16	$21^{\circ} 11'0''$	$20^{\circ} 36'1''$	$0^{\circ} 34'9''$
" " 29†	$21^{\circ} 19' \pm$	$20^{\circ} 25' \pm$	$0^{\circ} 54' \pm$
" December 26	$21^{\circ} 35'9''$	$20^{\circ} 2'6''$	$1^{\circ} 33'3''$

* *Monthly Notices*, vol. xiii. 1852 Nov. 12, p. 20.

† Value found approximately by interpolation.

We thus have the inequality

$$0^{\circ} 54' < 2^{\circ} 32' \cdot 9,$$

which shows that the difference in altitude of the Sun and Earth above the plane of the rings was smaller in November 1852 than in January 1851.

But the differences in altitude of the Sun and Earth above the plane of the rings do not solely affect the breadth of the "crape" ring's shadow about the lesser axis; they also disfigure its outline, by deviating it from concentricity with the apparent ellipses of the system. Neglecting the departure from centrality resulting from the position of *Saturn* in quadrature, we may state:—

(a) That with a Sun higher than the Earth, the shadow's breadth would be particularly reduced about the planet's limbs; while

(b) With a Sun lower than the Earth, its maximum breadth would, on the contrary, occur about the limbs.

Of these two appearances, the second is not a very unfrequent one,* but nothing like the former has ever been drawn, to the writer's knowledge. How, then, are we to account for the failure? We might, in reply, first point to the fact that the difference in length of the radii of the planet and the inner edge of the "dark" ring is not excessive, and that consequently the deformation could never be too marked either. This, however, does not suffice, and we may readily anticipate the action of optical phenomena. Irradiation, which is most active about the centre of *Saturn*, in reducing the breadth of the dusky shadow, must atone to some extent for the deformity, while the darkness of the planet's limb, in which the dusky projection shades off rather gently, might also act in the same direction.

We know from the investigations of Edouard Roche that the rings are composed of particles so small that the tide-generating force of the primary is absolutely powerless on them. Considered in connection with the fact that the Sun viewed from *Saturn* is not a point, but a very appreciable disc, this statement leads us to the conclusion that the modicum of shadow cast on the planet by each individual particle is not black, but penumbral† only,

* Under a large opening of the system the form (b) is often seen, even when the Sun and Earth have the same altitude above the plane of the ring. The phenomenon must, then, be due to the interference of the dark equatorial belt, on which the "crape" ring is projected.

† The writer's attention was recently drawn to the penumbral nature of the "crape" ring's shadow by a letter from Mr. Stanley Williams, in which it is said that, "Probably, if the particles composing the ring are very small, no actual black shadows would fall on the globe, but only penumbral shades, though the effect would be just the same." This quality of the shadow was also independently suspected by the writer three years previously, when he spoke of "the (penumbral) shadow on the planet of these same particles" (*Journal of the British Astronomical Association*, vol. vii. No. 5, p. 242).

the dusky projection to which the passage of the "crape" ring across the globe gives rise being thus formed of an integration of these infinitesimal penumbral shadings.

Observatoire Flammarion, Juvisy (S.-et-O.),
1899 August 3.

Ephemeris for Physical Observations of the Moon for the First Half of 1900. By A. C. D. Crommelin.

Greenwich Midnight.	1900.	Selenographical		Geocentric Libration		Combined Amount.	Direc- tion.
		Colong. of the Sun.	Lat.	Sel. Long. of the Earth.	Lat.		
Jan. 1		279°06	+0°59	-3°38	-3°04	4°55	132°0
2		291°26	+0°61	-1°88	-4°47	4°85	157°2
3		303°44	+0°64	-0°26	-5°61	5°62	177°4
4		315°62	+0°66	+1°35	-6°38	6°52	192°0
5		327°80	+0°69	+2°83	-6°71	7°28	202°9
6		339°97	+0°71	+4°08	-6°62	7°78	211°6
7		352°13	+0°74	+5°04	-6°12	7°93	219°5
8		4°28	+0°76	+5°69	-5°28	7°75	227°2
9		16°43	+0°79	+6°01	-4°15	7°30	235°4
10		28°58	+0°82	+6°04	-2°83	6°67	244°9
11		40°71	+0°85	+5°81	-1°38	5°97	256°6
12		52°85	+0°87	+5°36	+0°12	5°36	271°3
13		64°98	+0°90	+4°71	+1°58	4°97	288°5
14		77°12	+0°92	+3°90	+2°95	4°89	307°1
15		89°25	+0°95	+2°95	+4°18	5°12	324°8
16		101°38	+0°98	+1°89	+5°18	5°51	340°0
17		113°52	+1°00	+0°72	+5°95	5°99	353°1
18		125°65	+1°02	-0°52	+6°46	6°48	4°6
19		137°79	+1°05	-1°79	+6°69	6°92	15°0
20		149°94	+1°07	-3°08	+6°63	7°30	24°9
21		162°09	+1°09	-4°32	+6°29	7°63	34°5
22		174°24	+1°11	-5°45	+5°67	7°87	43°9
23		186°40	+1°13	-6°39	+4°78	7°98	53°2
24		198°56	+1°14	-7°07	+3°65	7°95	62°7
25		210°73	+1°16	-7°42	+2°31	7°78	72°7
26		222°90	+1°18	-7°34	+0°80	7°38	83°8
27		235°08	+1°19	-6°81	-0°80	6°85	96°7
28		247°28	+1°21	-5°80	-2°40	6°27	112°5
29		259°47	+1°22	-4°34	-3°89	5°83	131°9

Greenwich Midnight.	Selenographical		Geocentric Libration		Combined Amount.	Direc- tion.
	Colong. of the Sun.	Lat.	Sel. Long. of the Earth.	Lat.		
1900.						
Jan. 30	271°66	+ 1°24	- 2°53	- 5°14	5°73	153°8
31	283°86	+ 1°25	- 0°51	- 6°04	6°06	175°2
Feb. 1	296°05	+ 1°26	+ 1°54	- 6°52	6°70	193°3
2	308°24	+ 1°28	+ 3°43	- 6°54	7°38	207°7
3	320°43	+ 1°30	+ 5°01	- 6°12	7°90	219°3
4	332°61	+ 1°31	+ 6°19	- 5°33	8°16	229°3
5	344°78	+ 1°33	+ 6°91	- 4°23	8°10	238°5
6	356°94	+ 1°35	+ 7°20	- 2°93	7°77	247°9
7	9°10	+ 1°36	+ 7°09	- 1°50	7°24	258°1
8	21°25	+ 1°38	+ 6°65	- 0°04	6°65	269°6
9	33°40	+ 1°40	+ 5°95	+ 1°40	6°11	283°2
10	45°54	+ 1°41	+ 5°06	+ 2°75	5°76	298°5
11	57°69	+ 1°43	+ 4°03	+ 3°95	5°64	314°4
12	69°83	+ 1°44	+ 2°90	+ 4°97	5°76	329°7
13	81°97	+ 1°45	+ 1°70	+ 5°76	6°00	343°6
14	94°11	+ 1°46	+ 0°47	+ 6°29	6°31	355°7
15	106°25	+ 1°47	- 0°80	+ 6°54	6°58	7°0
16	118°39	+ 1°48	- 2°07	+ 6°52	6°84	17°6
17	130°54	+ 1°49	- 3°33	+ 6°21	7°05	28°2
18	142°69	+ 1°50	- 4°55	+ 5°63	7°23	38°9
19	154°84	+ 1°50	- 5°67	+ 4°80	7°43	49°7
20	167°00	+ 1°51	- 6°65	+ 3°74	7°64	60°6
21	179°16	+ 1°51	- 7°40	+ 2°48	7°81	71°5
22	191°33	+ 1°52	- 7°85	+ 1°07	7°92	82°2
23	203°51	+ 1°52	- 7°92	- 0°44	7°94	93°2
24	215°69	+ 1°52	- 7°54	- 1°97	7°79	104°6
25	227°88	+ 1°52	- 6°66	- 3°43	7°49	117°2
26	240°08	+ 1°53	- 5°28	- 4°72	7°08	131°8
27	252°28	+ 1°53	- 3°47	- 5°72	6°69	148°8
28	264°49	+ 1°53	- 1°36	- 6°33	6°48	167°9
Mar. 1	276°69	+ 1°53	+ 0°87	- 6°49	6°55	187°6
2	288°90	+ 1°53	+ 3°01	- 6°19	6°88	205°9
3	301°10	+ 1°54	+ 4°85	- 5°46	7°30	221°6
4	313°30	+ 1°54	+ 6°27	- 4°38	7°64	235°1
5	325°49	+ 1°54	+ 7°18	- 3°07	7°80	246°9
6	337°68	+ 1°55	+ 7°59	- 1°62	7°75	258°0
7	349°86	+ 1°55	+ 7°53	- 0°13	7°53	269°0
8	2°04	+ 1°55	+ 7°08	+ 1°33	7°20	280°6

Greenwich Midnight.	Selenographical Colong. Lat. of the Sun.		Geocentric Libration Sel. Long. Lat. of the Earth.		Combined Amount.	Direction.
1900.						
March 9	14°21	+ 1°55	+ 6°32	+ 2°69	6°87	293°1
10	26°37	+ 1°55	+ 5°33	+ 3°89	6°60	306°1
11	38°53	+ 1°55	+ 4°19	+ 4°91	6°46	319°5
12	50°69	+ 1°55	+ 2°96	+ 5°70	6°42	332°6
13	62°85	+ 1°55	+ 1°69	+ 6°24	6°46	344°8
14	75°01	+ 1°55	+ 0°40	+ 6°51	6°52	356°5
15	87°16	+ 1°54	- 0°86	+ 6°50	6°56	7°5
16	99°32	+ 1°54	- 2°09	+ 6°21	6°55	18°6
17	111°48	+ 1°53	- 3°28	+ 5°64	6°52	30°2
18	123°63	+ 1°52	- 4°39	+ 4°82	6°52	42°3
19	135°79	+ 1°51	- 5°41	+ 3°77	6°60	55°1
20	147°95	+ 1°50	- 6°29	+ 2°53	6°78	68°1
21	160°12	+ 1°49	- 6°99	+ 1°15	7°08	80°7
22	172°30	+ 1°48	- 7°43	- 0°32	7°44	92°5
23	184°48	+ 1°47	- 7°55	- 1°80	7°76	103°4
24	196°66	+ 1°46	- 7°28	- 3°23	7°97	113°9
25	208°86	+ 1°45	- 6°57	- 4°51	7°96	124°4
26	221°06	+ 1°44	- 5°40	- 5°55	7°74	135°8
27	233°27	+ 1°42	- 3°83	- 6°25	7°33	158°5
28	245°49	+ 1°41	- 1°92	- 6°54	6°81	163°6
29	257°71	+ 1°40	+ 0°15	- 6°37	6°37	181°3
30	269°93	+ 1°39	+ 2°20	- 5°75	6°15	200°9
31	282°15	+ 1°38	+ 4°05	- 4°75	6°25	220°5
April 1	294°27	+ 1°37	+ 5°53	- 3°43	6°51	238°2
2	306°59	+ 1°36	+ 6°57	- 1°94	6°85	253°6
3	318°80	+ 1°35	+ 7°11	- 0°38	7°12	266°9
4	331°01	+ 1°34	+ 7°17	+ 1°16	7°26	279°2
5	343°21	+ 1°33	+ 6°82	+ 2°59	7°30	290°8
6	355°41	+ 1°32	+ 6°13	+ 3°85	7°23	302°1
7	7°60	+ 1°31	+ 5°17	+ 4°91	7°13	313°5
8	19°78	+ 1°29	+ 4°03	+ 5°74	7°01	324°9
9	31°96	+ 1°28	+ 2°78	+ 6°31	6°90	336°2
10	44°14	+ 1°26	+ 1°49	+ 6°60	6°76	347°3
11	56°32	+ 1°24	+ 0°21	+ 6°62	6°62	358°2
12	68°49	+ 1°23	- 1°03	+ 6°35	6°44	9°2
13	80°66	+ 1°21	- 2°19	+ 5°79	6°19	20°7
14	92°83	+ 1°19	- 3°25	+ 4°98	5°95	33°1
15	105°00	+ 1°17	- 4°20	+ 3°93	5°75	46°9

Greenwich Midnight.	Selenographical Colong. of the Sun.		Geocentric Libration Sel. Long. of the Earth.		Combined Amount.	Direction.
1900. April 16	117°17'	+ 1°14'	- 5°01'	+ 2°68'	5°68'	61°9'
17	129°34'	+ 1°12'	- 5°67'	+ 1°28'	5°81'	77°3'
18	141°52'	+ 1°10'	- 6°15'	- 0°20'	6°16'	91°9'
19	153°70'	+ 1°08'	- 6°40'	- 1°70'	6°62'	104°9'
20	165°89'	+ 1°05'	- 6°39'	- 3°14'	7°12'	116°2'
21	178°09'	+ 1°03'	- 6°07'	- 4°43'	7°51'	126°1'
22	190°29'	+ 1°01'	- 5°43'	- 5°50'	7°72'	135°4'
23	202°49'	+ 0°99'	- 4°44'	- 6°26'	7°67'	144°7'
24	214°71'	+ 0°97'	- 3°13'	- 6°64'	7°34'	154°8'
25	226°93'	+ 0°94'	- 1°58'	- 6°59'	6°78'	166°5'
26	239°17'	+ 0°92'	+ 0°11'	- 6°11'	6°11'	181°0'
27	251°40'	+ 0°90'	+ 1°80'	- 5°21'	5°51'	199°1'
28	263°64'	+ 0°88'	+ 3°36'	- 3°97'	5°20'	220°2'
29	275°88'	+ 0°87'	+ 4°66'	- 2°49'	5°28'	241°9'
30	288°12'	+ 0°85'	+ 5°60'	- 0°88'	5°67'	261°1'
May 1	300°35'	+ 0°83'	+ 6°14'	+ 0°73'	6°18'	276°8'
2	312°58'	+ 0°81'	+ 6°25'	+ 2°27'	6°66'	289°9'
3	324°81'	+ 0°79'	+ 5°99'	+ 3°64'	7°01'	301°3'
4	337°03'	+ 0°77'	+ 5°38'	+ 4°79'	7°20'	311°7'
5	349°24'	+ 0°75'	+ 4°49'	+ 5°70'	7°25'	321°8'
6	1°45'	+ 0°72'	+ 3°41'	+ 6°35'	7°21'	331°8'
7	13°66'	+ 0°70'	+ 2°19'	+ 6°70'	7°04'	341°9'
8	25°86'	+ 0°67'	+ 0°93'	+ 6°77'	6°83'	352°2'
9	38°05'	+ 0°65'	- 0°34'	+ 6°55'	6°56'	3°0'
10	50°25'	+ 0°62'	- 1°53'	+ 6°05'	6°24'	14°2'
11	62°44'	+ 0°60'	- 2°61'	+ 5°27'	5°88'	26°4'
12	74°62'	+ 0°57'	- 3°54'	+ 4°25'	5°53'	39°8'
13	86°81'	+ 0°54'	- 4°30'	+ 3°01'	5°25'	55°0'
14	98°99'	+ 0°51'	- 4°86'	+ 1°60'	5°11'	71°8'
15	111°18'	+ 0°48'	- 5°21'	+ 0°09'	5°21'	89°0'
16	123°36'	+ 0°45'	- 5°34'	- 1°46'	5°54'	105°3'
17	135°55'	+ 0°42'	- 5°23'	- 2°94'	6°00'	119°3'
18	147°74'	+ 0°39'	- 4°91'	- 4°29'	6°53'	131°2'
19	159°94'	+ 0°36'	- 4°34'	- 5°42'	6°94'	141°3'
20	172°14'	+ 0°34'	- 3°57'	- 6°23'	7°17'	150°2'
21	184°35'	+ 0°31'	- 2°60'	- 6°69'	7°17'	158°8'
22	196°57'	+ 0°28'	- 1°47'	- 6°74'	6°89'	167°7'
23	208°80'	+ 0°26'	- 0°24'	- 6°37'	6°38'	177°8'

Greenwich Midnight.		Selenographical		Geocentric Libration		Combined Amount.	Direc- tion.
		Colong. of the Sun.	Lat.	Sel. Long. of the Earth.	Lat.		
1900.							
May	24	221°03	+0°23	+1°03	-5°59	5°70	190°4
	25	233°27	+0°21	+2°25	-4°46	5°00	206°8
	26	245°52	+0°19	+3°35	-3°06	4°54	227°6
	27	257°76	+0°16	+4°25	-1°49	4°50	250°7
	28	270°01	+0°14	+4°90	+0°15	4°90	271°8
	29	282°26	+0°12	+5°24	+1°74	5°52	288°4
	30	294°51	+0°09	+5°26	+3°21	6°16	301°4
	31	306°75	+0°07	+4°96	+4°47	6°68	312°0
June	1	318°99	+0°04	+4°37	+5°49	7°02	321°5
	2	331°23	+0°02	+3°52	+6°23	7°16	330°5
	3	343°46	-0°01	+2°47	+6°68	7°12	339°7
	4	355°68	-0°03	+1°29	+6°83	6°95	349°3
	5	7°90	-0°06	+0°04	+6°69	6°69	359°7
	6	20°11	-0°09	-1°21	+6°27	6°39	10°9
	7	32°32	-0°12	-2°38	+5°57	6°05	23°1
	8	44°53	-0°15	-3°42	+4°61	5°74	36°6
	9	56°73	-0°18	-4°26	+3°43	5°47	51°2
	10	68°93	-0°21	-4°86	+2°06	5°27	67°0
	11	81°12	-0°24	-5°17	+0°56	5°20	83°8
	12	93°31	-0°26	-5°20	-1°01	5°30	101°0
	13	105°50	-0°29	-4°93	-2°55	5°55	117°4
	14	117°69	-0°32	-4°38	-3°97	5°91	132°2
	15	129°88	-0°35	-3°60	-5°17	6°29	145°2
	16	142°07	-0°38	-2°64	-6°08	6°63	156°5
	17	154°27	-0°41	-1°56	-6°62	6°81	166°7
	18	166°48	-0°44	-0°44	-6°75	6°76	176°3
	19	178°70	-0°46	+0°68	-6°46	6°50	186°0
	20	190°92	-0°48	+1°74	-5°78	6°04	196°8
	21	203°16	-0°51	+2°68	-4°75	5°45	209°4
	22	215°39	-0°53	+3°48	-3°44	4°89	225°3
	23	227°64	-0°55	+4°12	-1°95	4°55	244°7
	24	239°89	-0°57	+4°57	-0°36	4°58	265°5
	25	252°14	-0°59	+4°81	+1°23	4°96	284°3
	26	264°39	-0°61	+4°83	+2°72	5°54	299°4
	27	276°64	-0°63	+4°61	+4°04	6°13	311°2
	28	288°90	-0°66	+4°16	+5°14	6°61	321°0
	29	301°15	-0°68	+3°49	+5°97	6°90	329°7
	30	313°39	-0°70	+2°60	+6°51	7°01	338°2
July	1	325°64	-0°72	+1°54	+6°74	6°91	347°1

The longitudes are reckoned in the plane of the Moon's equator, the axis of reference being the radius which passes through the mean centre of the visible disc. This axis therefore rotates with the Moon, and is not fixed in space.

The inclination of the Moon's equator to the ecliptic is taken as $1^{\circ}523$, the value used in the *Connaissance des Temps*, that given by the *Nautical Almanac* being $1^{\circ}536$.

I have taken the value of the physical libration in longitude from the *Berliner Jahrbuch* for the days on which it is tabulated there, the values on intermediate days being found by a graphical method. In other words, the whole of Professor Franz's formula for the physical libration has been used, instead of the principal term alone, as heretofore.

The physical libration in latitude has been applied in the above ephemeris for the first time, its value being likewise taken from the *Berliner Jahrbuch*. But in each case the sign of the libration as given in the *Jahrbuch* requires to be changed to reduce it to the system used here. Some doubts having been expressed to me as to whether the physical libration has hitherto been applied with the correct sign, I consulted Professor Franz, who replied that the sign heretofore used was correct, and that the sign of the physical libration in the *Berliner Jahrbuch* requires to be reversed both in longitude and latitude, in order to reduce it to the system used in the above ephemeris.

The colongitude of the Sun is 90° (or 450°) minus his selenographical longitude. It also is the selenographical longitude of the morning terminator reckoned eastward from the mean centre of the disc. Hence its value is approximately $270^{\circ}, 0^{\circ}, 90^{\circ}, 180^{\circ}$ at new Moon, first quarter, full Moon, last quarter respectively. The longitude of the evening terminator is of course 180° greater or less than that of the morning one.

When the geocentric libration in longitude is positive, the region brought into view is on the west limb; when negative, on the east.

When the geocentric libration in latitude is positive, the region brought into view is at the Moon's north pole; when negative, at the south.

The column "Combined Amount" gives the distance between the apparent and mean centres of the disc, and the column "Direction" gives the position-angle of the apparent centre from the mean centre, or, which is the same thing, the position-angle of the region which is most carried into view by libration. The angles are reckoned eastward from the northern extremity of the Moon's axis.

The terms "East" and "West" are used throughout with reference to our sky, and not as they would appear to an observer on the Moon.

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